



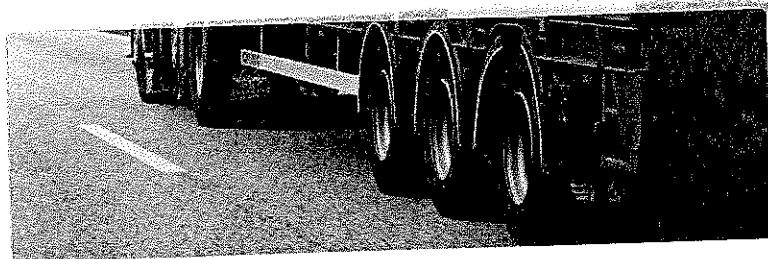
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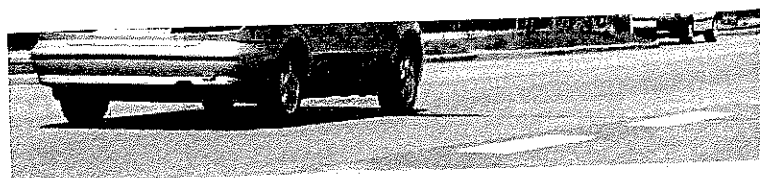
LNEC, LISBOA, 3 de Dezembro de 2007



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Fundo para o Desenvolvimento
das Ciências da Construção



CONTRIBUTION OF ALTERNATIVE ROAD SURFACES TO NOISE ABATEMENT

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ABSTRACT

The increase of noise due to traffic particularly in urban areas has led road administrations to look for low noise surfaces in order to reduce noise impact and to improve environmental quality.

This paper aims at assessing the effect of alternative road surfaces on noise abatement. It presents the main results obtained with two distinct experiments, originally intended for other purposes, which address a significant number of non conventional road surfaces.

These experiments included nine road surfaces: three of them were gap graded, three contained rubberized asphalt, one had porous asphalt and two had dense asphalt.

On these road sections the tyre-road noise generated by two-axle heavy trucks and three-axle heavy trucks and several light vehicles at three levels of speed were measured by means of pass-by tests. Surface texture tests were also performed. The results focused on: i) noise level variation versus speed; ii) estimated noise level for each speed level versus type of surface; iii) the variation of estimated noise level with regards to a reference surface.

The best performances were achieved by gap graded mixtures with and without rubberized binder and small grain sizes. The fair behaviour shown by the porous asphalt indicates that the surface texture determined by the grain size seems to influence the noise level more than porosity.

Further research on tyre-surface noise should include wide ranges of testing speeds for heavy vehicles, tests with the surface wet, tests that can provide texture spectrum and sound absorption tests.

OVERVIEW

The total noise produced by vehicles comes from several sources, such as engines, exhaust and power train system noise, tyre-surface noise generated by the interaction of tyre and road and even the wind noise. For speeds above 40 to 50 km/h the tyre-surface contact noise is predominant (Bendtsen et al., 2006). The tyre-surface noise generation mechanisms come from radial and tangential vibrations of the tyre tread as a result of the impact and the adhesion of the treads on the surface, and from air vibrations around the tyre and in the grooves and cavities of the tyre tread. These mechanisms may be amplified by the horn effect and by the acoustical and mechanical impedance of the surface (Sandberg et al., 2002) which are affected by the following parameters:

- surface characteristics – aggregate gradation (Bendtsen, 2006), texture (Sandberg et al., 2002), porosity, age (FEHRL, 2006), stiffness (Houari, 2004), distresses (Berengier, 2005);
- vehicles – type of vehicle (Descornet, 2005), tyre (Pucher et al., 2006), speed (Haberl et al., 2005);
- weather conditions – wind (Watts, 2005), temperature (Anfosso-Lédée, 2001), water on the surface (Sandberg et al., 2002; Freitas et al., 2006);
- drivers' behaviour (Mancosu, 1999).

For the assessment of the tyre-surface noise there are two main standardized methods, consisting of pass-by and mobile measurements: the Statistical Pass-By method (ISO 11819-1:1997) and the Close-Proximity method (draft ISO/CD 11819-2). The Controlled Pass-by Method is a variant of the

first method that uses a small number of controlled vehicles instead of a statistical selection from normal traffic. Using test vehicles and test drivers to produce pass-bys at pre-defined speeds simplifies and shortens the measurement procedure. These methods are often used for the comparison of road surfaces. According to Sandberg et al. (2002), a low noise road surface is a road surface which, when interacting with a rolling tyre, influences vehicle noise in such a way as to cause at least 3 dB(A) (half power) lower vehicle noise than that obtained on a conventional and most common road surface.

Several studies carried out in roads with different types of surfaces and ages usually show that dense asphalt concrete, stone mastic asphalt and surface dressings are the ones that generate more noise contrarily to double and single porous asphalt, thin layers and poroelastic surfaces (Anderson et al., 2006; Descornet et al., 2006; Bartolomaeus, 2006).

In the first group the aggregate size, which is usually big, the low porosity and the positive texture are factors that greatly contribute to high noise levels. In the second group, the reduction of noise generated by the texture impact mechanism is due to the small aggregate size. The gap-graded nature (indented or negative texture) also gives them appropriate air drainage, properties that contribute to the reduction of air-pumping noise and other similar mechanisms of noise generation (SILVIA, 2006).

Among the most silent layers, the poroelastic one outstands, since reductions up to 12 dB were achieved in experiments carried out in Japan, the Netherlands and Sweden (Sandberg and Kalman, 2005) as a result of their composition. These experimental poroelastic mixtures are characterized by high percentages of rubber granules, up to 90% by weight, and by high void volume. This combination leads to a reduced durability that needs to be augmented.

In its turn, Donovan (2005) found noise levels similar to those of the porous asphalt on dense asphalt concrete surfaces with rubberized binder either in the United States or in Europe. In Portugal two studies which included this type of mixtures were carried out. The first one compared a gap graded rubber asphalt with a “rough” dense asphalt and with cement concrete. The other one assessed the noise produced by a porous rubber asphalt mixture. In the first case, abatements of 5 to 8 dB(A) and 8 to 10 dB(A) were stated (Ruivo, 2004). In the second case, a reduction of 3 to 5 dB(A) was reported (Gomes et al., 2006).

This paper intends to give a number of insights into this issue by comparing noise levels measured in dense asphalt concrete, thin layers composed of gap graded asphalt concrete and rubberized asphalt concrete and porous asphalt surfaces.

STUDY METHODOLOGY

This study gathers the results obtained from two separate studies carried out on eight roads in the northern of Portugal. In both studies the Controlled Pass-by Method was adopted, what allowed controlling several testing factors such as category, speed and load of the vehicles, the number of pass-bys of each type of vehicle, type and wearing of the tires, the noise generated by the engine and the wet/dry condition of the surface.

The pass-bys were effectuated with the engine switched on at a speed range from 50 km/h to 130 km/h. A microphone was positioned 1.2 m above the pavement surface and 7.5 m from the centre of the carriageway. The following measurements were made on each pass-by: maximum noise level and corresponding noise spectrum, vehicle speed, air and surface temperatures and wind speed. The surface properties such as the mean profile depth and skid resistance were also measured. The mixture properties were kindly provided by the Road Administrations.

In view of the fact that these experiments were carried out in different category roads (national roads and motorway) and for comparison purposes, this study will adopt the following reference speeds: 50 km/h, 70 km/h and 90 km/h.

The first experiment included seven in-service road sections, the surface layer of which is composed of three main types of mixtures: i) one on dense asphalt concrete; ii) three on gap graded asphalt; iii) three on gap graded asphalt rubber.

The tests were performed with three vehicles (Figure 1) grouped into the following categories, as recommended by the standard ISO 11819-1:1997(E):

- Cars and other light vehicles (L_1) – 1 Volkswagen Polo, 1 Nissan Strakar;
- Dual-axle heavy vehicles (L_{2a}) – 1 Volvo;
- Multi-axle heavy vehicles (L_{2b}) – none.

The testing speed took into account the legal speed limits on national roads:

- LV (P) – four pass-bys at 50 km/h, 70 km/h and 90 km/h;
- HV – four pass-bys at 50 km/h, 70 km/h;
- LV (S) – two pass-bys at 50 km/h, 70 km/h and 90 km/h.

In each section the ordinary traffic was stopped during testing in both directions. Since all the roads have an important traffic flow, five sections were tested at night in order to avoid unnecessary nuisance to users. On the whole 188 vehicle pass-bys were effectuated.



Figure 1 – Testing vehicles for the experiment 1

The second experiment was carried out on a motorway under construction, in the northern of Portugal. Thus, it was possible to set two consecutive road sections, one with a dense asphalt surface and the other with a porous asphalt surface.

In this case, the tests were performed with six types of vehicles (Figure 2) grouped as follows:

- Category 1: cars and other light vehicles (L_1) – 1 Citroen XSara, 1 Volvo S40, 1 Nissan Terrano, 1 Renault Traffic;
- Dual-axle heavy vehicles (L_{2a}) – 1 Mercedes;
- Multi-axle heavy vehicles (L_{2b}) – 1 Scania.



Figure 2 – Testing vehicles for the experiment 2

The testing speed adopted was within the limits recommended at ISO 11819-1:1997(E):

- Medium road speed – average speed of 65 km/h to 99 km/h;
- High road speed – more than 100 km/h.

A total of 207 valid vehicles pass-bys were effectuated either with a dry surface or wetted by a water truck. For comparison purposes, this paper will be focused on pass-bys effectuated by light vehicles and dual axle vehicles.

TESTING CONDITIONS

Road sections and pavement surface

The selection of the testing sections regarded four main conditions: i) type and condition of the surface; ii) security concerning the length required for accelerating and breaking; iii) presence of high reflective objects; iv) the slope of the road. In Figure 3 the test sites and the corresponding aspect of the surface are depicted.

The main properties of the mixtures, such as the maximum aggregate size (MAS), porosity (P), bitumen percentage by total weight (BP), rubber percentage by weight of the bitumen (RP) and age, are also represented. In the same figure each surface is identified by the acronym of the corresponding mixture followed by the MAS.


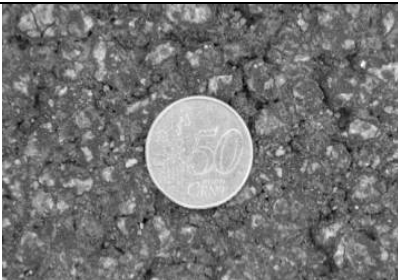



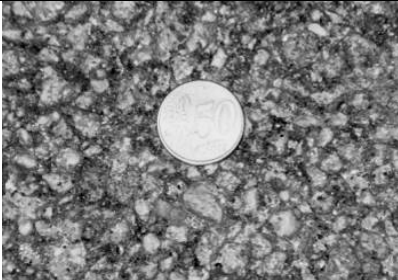

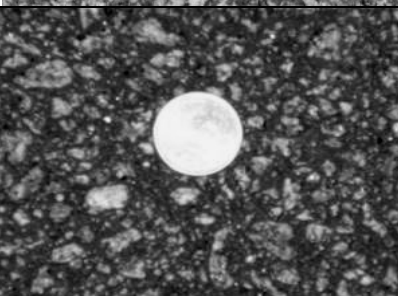
		Surface 1: S1(GG12) Gap graded (rough) MAS: 12 mm P: 3.6% BP: 5.1% Age: 1 year
		Surface 2: S2(GG6) Gap graded MAS: 6 mm P: 6.6% BP: 6.2% Age: 2 years
		Surface 3: S3(RAR15) “Rough” asphalt rubber concrete MAS: 15 mm P: < 5.0 % BP: 7.0 % RP: 18% Age: 7 years
		Surface 4: S4(DA16) Dense Asphalt MAS: 16 mm P: 5.0% BP: 4.9% Age: 10 years

Figure 3 – Test sites, aspect and properties of the surface (continues)


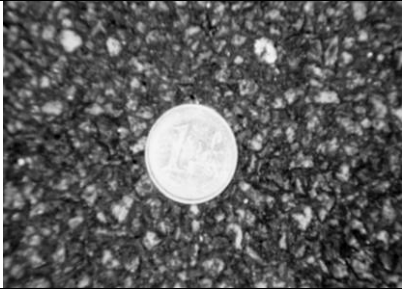








		<p>Surface 5: S5(GG7)</p> <p>Gap graded MAS: 7 mm P: 6.1% BP: 6.1% Age: 4 years</p>
		<p>Surface 6: (GGAR12)</p> <p>Gap graded with asphalt rubber MAS: 12 mm P: 13.0% BP: 9.0% RP: 20% Age: <1 year</p>
		<p>Surface 7: (GGAR10)</p> <p>Gap graded with asphalt rubber MAS: 10 mm P: 14.0% BP: 9.0% RP: 20% Age: <1 year</p>
		<p>Surface 8: (DA16*)</p> <p>Dense asphalt MAS: 16 mm P: 4.5% BP: 5.1% Age: under construction</p>
		<p>Surface 9: (PA15)</p> <p>Porous asphalt MAS: 10 mm P: 22.0% BP: 4.5% Age: under construction</p>

Figure 3 – Test sites, aspect and properties of the surface (continuation)

Surfaces S1, S2 and S5 are thin layers composed of gap graded asphalt mixtures (GG) with less than 6% of voids. Surfaces S3, S6 and S7 are also thin layers. Within this set, surface S3 is a “rough” asphalt rubber concrete (RAR) and surfaces S6 and S7 are gap graded asphalt rubber mixtures (GGAR), the void content of which is about 13%. The rubber content by weight of bitumen is 18% to

20%. The thickness range of these six layers is [2.5 - 4] cm. Surface S9 regards the porous asphalt (PA) with 4 cm of thickness and 22.0% of voids. Surfaces S4 and S8 are composed of dense asphalt concrete (DA), which is the most common type of surface. It is used in all types of roads (rural or urban) and due to its ordinary properties they will be considered as a reference for noise levels.

The mean profile depth, converted then to the estimated texture depth (ETD), was measured with a High Speed Profilometer according to the Standard ISO 13473-1:1997, in a length of 30 m before and after the microphone location on surfaces S1 to S7. For surfaces S8 and S9 the Sand Patch Method (ASTM E965-96, 2006) was used for measuring the texture depth every 12.5 m at three cross section locations. The skid resistance was measured with the British Pendulum according to the standard ASTM E303 - 93 (2003). In Table 1 the average of the results for these properties is presented.

Table 1 – Estimated texture depth and skid resistance of the surface

Surface	Estimated texture depth (mm)	Skid resistance at 20°C (BPN)
S1(GG12)	1.0	54.5
S2(GG6)	0.6	52.2
S3(RAR15)	0.6	50.6
S4(DA16)	0.7	51.4
S5(GG7)	0.6	51.8
S6(GGAR12)	0.7	50.0
S7(GGAR10)	0.8	52.6
S8(DA16*)	0.9	70.0
S9(PA15)	1.5	70.0

Despite their differences in age and porosity, the ETD is similar except for surfaces S1 and S9. The former is notoriously rougher than the others of the same type and the latter is porous and therefore the ETD is significantly higher, although values higher than 0.9 mm should be found when dealing with gap graded rubber asphalt mixtures.

Weather

Temperature, wind speed and water on surface are the weather factors that may determine noise. If temperature or wind speed values change significantly corrections to a reference value should be made. The Directive 2001/43/EC of the European Parliament recommends the correction of temperature to the reference value of 20°C and testing with wind speeds below 5 m/s.

Throughout both testing periods the wind speed was always inferior to 4 m/s. The effect of testing temperature was not taken into account because the variation in noise level is much smaller than the data bias (< 1dB(A)).

ANALYSIS OF THE RESULTS

Noise level versus speed

In Figures 3 and 4 the noise level versus speed for all vehicles measured in each section is presented. The trend line and the corresponding regression parameters are also presented.

For presentation purposes, the linear regression analysis was preferred to a regression with the logarithm of the vehicle speed as the fitting quality is nearly the same for the adopted speed range. The fitting quality in the first experiment was better than in the second. This may have been due to the reduced number of vehicles and drivers and testing speeds in the first experiment (Figure 3) and to the higher variability of testing speed in the second (Figure 4). Another possible cause for the variability of the results was the difficulty in controlling particularly the truck acceleration, due to limitations regarding the geometry and the length of the section.

The curve slope indicates the variation of noise level with speed. When the light vehicles are concerned, noise mostly increases with speed on surface S4(DA16). The opposite is stated on surface

S7(GGAR10), although the slope differences are not significant. Therefore, for light vehicles the variation of the noise level with speed is similar in all surfaces, including S8(DA16*) and S9(PA15) when the surface is wet.

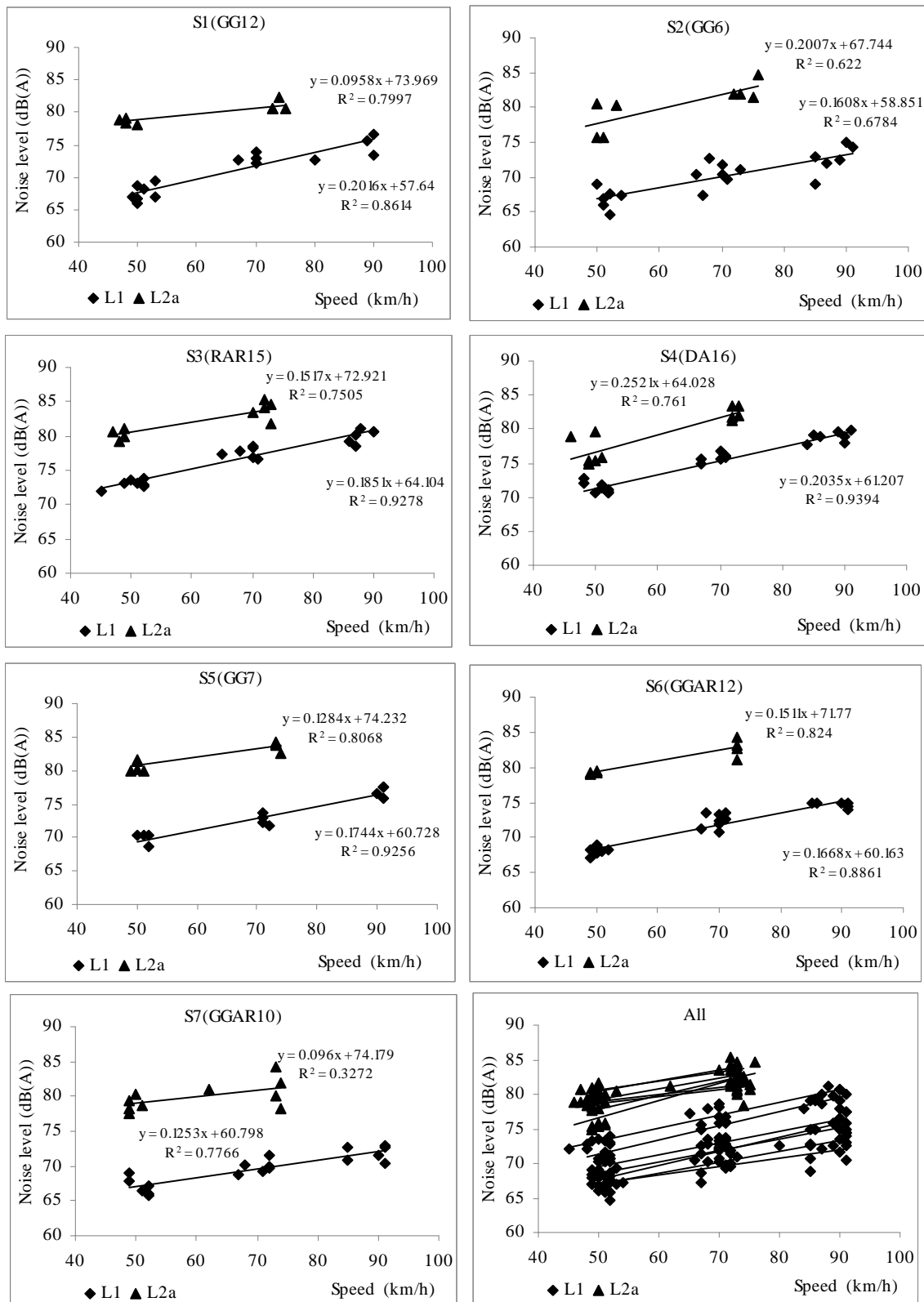


Figure 3 – Noise level versus speed for all vehicles and sections in the first experiment

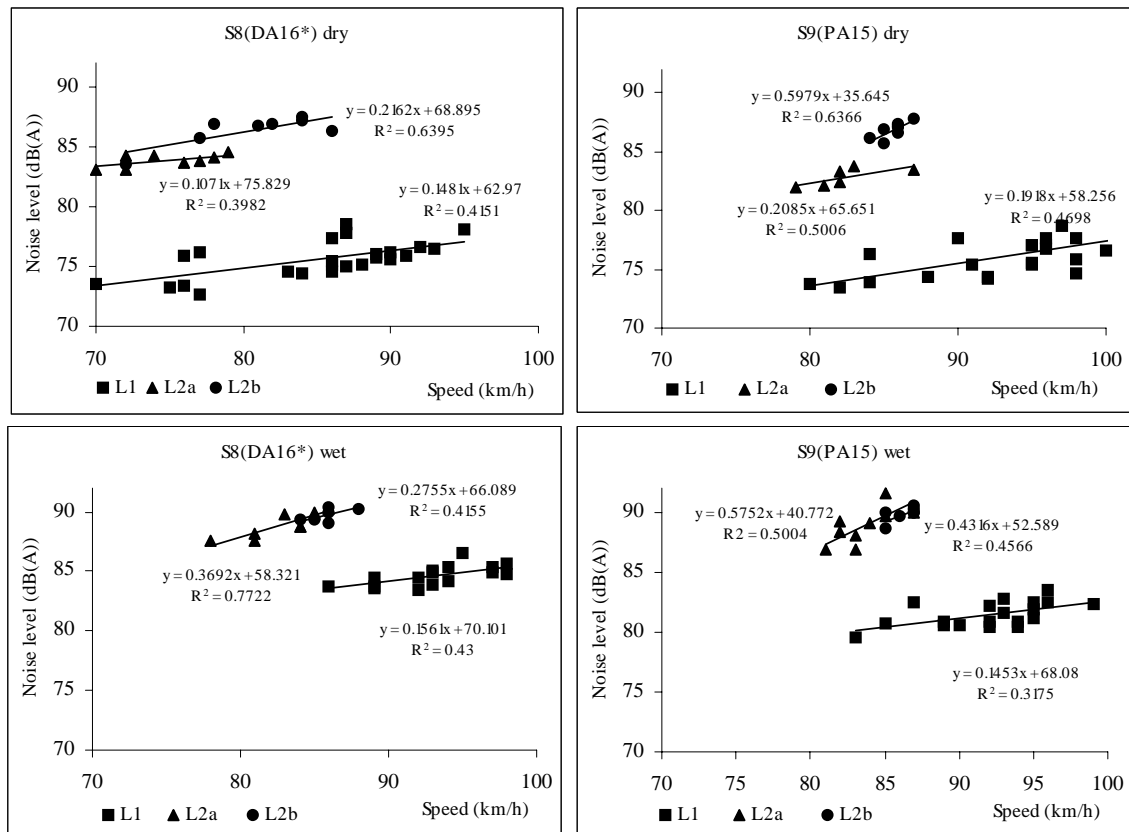


Figure 4 – Noise level versus speed for all vehicles in the second experiment

The curve slope for the vehicle category L2a is generally slightly smaller than for category L1 showing that noise level is less dependent on speed if the surface is dry. The results obtained for wet surfaces S8(DA16*) and S9(PA15), correspondingly 0.37 and 0.58, are a fine indication which allows stating that noise level highly depends on speed.

The curve slope for the vehicle category L2b and for the porous asphalt S9(PA15) is considerably higher than for categories L1 and L2a either with the surface dry or wet.

Estimated noise level versus type of surface

For this analysis, the noise level was estimated for each nominal speed level (50 km/h, 70 km/h and 90 km/h) and for each type of vehicle using the fitted curves discussed above. Figure 5 depicts the results sorted into the increasing MAS.

As far as light vehicles are concerned, surfaces S2(GG6) and S7(GGAR10) generate the lowest noise levels the range of which is [66 - 74] dB(A) for the three speed levels. These are followed by surfaces S1(GG12), S6(GGAR12) and S9(PA15), the range of which is [67 - 78] dB(A) and reference surfaces S4(DA16) and S8(DA16*), the range of which is [70 - 80] dB(A). Finally, surface S3(RAR15) generates the highest noise levels the range of which is [73 - 81] dB(A). For these conditions, the difference between the highest and the lowest value increases with speed and ranges from 6.5 dB(A) to 8.7 dB(A).

For what respects the heavy vehicles, three aspects must be taken into account. For this type of vehicles, the tyre-road noise may not surpass engine noise at 50 km/h. The differences in the noise level may be due to engine noise variation at the different pass-bys, what could be checked by switching off the engine during the pass-by. In addition, the testing range of the first experiment does not include speeds above 70 km/h and the second experiment does not include speeds under 70 km/h. Therefore, the results obtained for the speeds of 50 km/h and 90 km/h may be less reliable than for 70 km/h due to the extrapolation of the noise level.

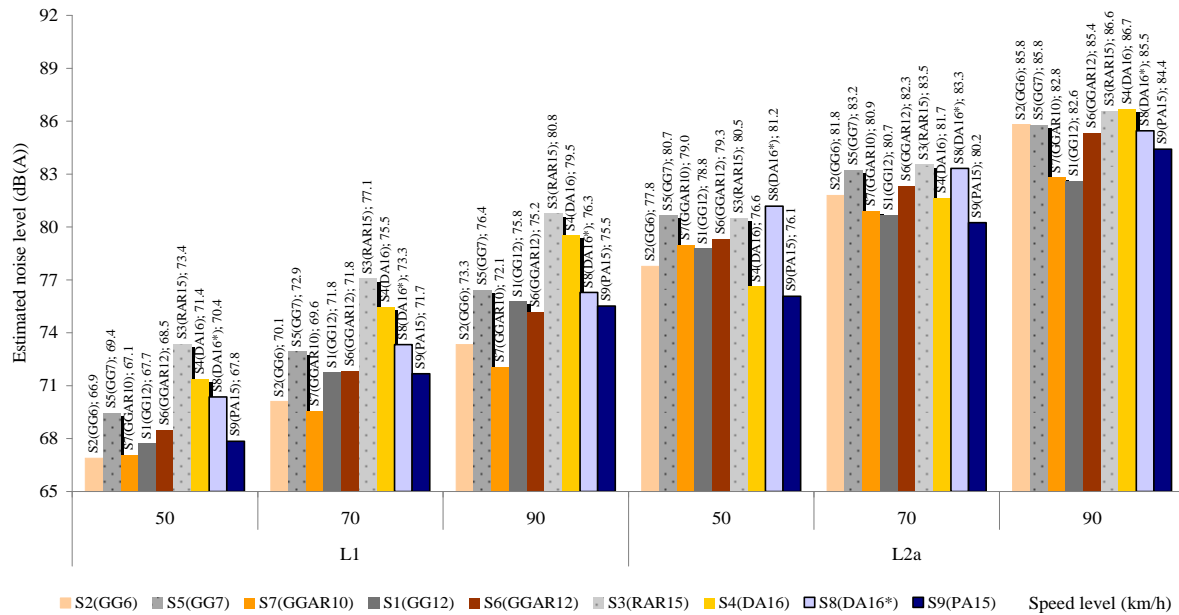


Figure 5 – Estimated noise level versus speed in each section (sorted into the increasing MAS)

In this case, at a speed level of 50 km/h, surfaces S9(PA15) and S4(DA16) generate the lowest noise levels while surfaces S3(RAR15), S5(GG7) and S8(DA16*) generate the highest noise levels, which are estimated in about 80 dB(A).

At a speed level of 70 km/h surfaces S1(GG12), S7(GGAR10) and S9(PA15) have the best results with about 80 dB(A) and surfaces S3(RAR15), S5 (GG7) and S8(DA16*) have the highest values (83 dB(A)).

At a speed level of 90 km/h surfaces S1(GG12) and S7(GGAR10) followed by surface S9(PA15) are the most silent.

In this case, the difference between the highest and the lowest value is significantly smaller. Nevertheless, these differences are in increasing order of speed 4.6 dB(A), 3.3 dB(A) and 4.1 dB(A).

Estimated noise level versus reference surface

With this analysis it is intended to determine the benefits on noise abatement for the tested surfaces with reference to the most common surface used in Portugal. Surfaces S4(DA16) and S8(DA16*) may be taken as a reference. However, due to their important difference of age (10 years) and exposure to traffic, the first one was adopted for this analysis.

In Figure 6 the variation of the average noise level for each nominal speed level (50 km/h, 70 km/h and 90 km/h) taking surface S4(AD16) as a reference is depicted. The negative values indicate that the noise level is smaller than the one of the surface of reference.

In relative terms, Figure 5 clearly shows that surface S3(RAR15) increases noise regardless the testing conditions.

At 50 km/h, and for the heavy vehicle, all surfaces but S9(PA15) generate more noise than the surface of reference (S4(DA16)). At 70 km/h surfaces S1(GG12), S7(GGAR10) and S9(PA15) slightly reduce noise (less than 1.5 dB(A)). At 90 km/h the estimated noise level indicates a reduction of about 4 dB(A) for surfaces S7(GGAR10) and S1(GG12).

As far as light vehicles are concerned, all the surfaces significantly produced less noise than the surface of reference, with the exception of surface S3(RAR15). Surface S2(GG6) and surface S7(GGAR10) obtained quite similar results. The noise abatement for these surfaces, for speeds of 50 km/h, 70 km/h and 90 km/h, was about 5 dB(A), 6 dB(A) and more than 7 dB(A), respectively. Surfaces S1(GG12), S6(GGAR12) and S9(PA15) also had similar results, comprising reductions between 3 and 4.5 dB(A).

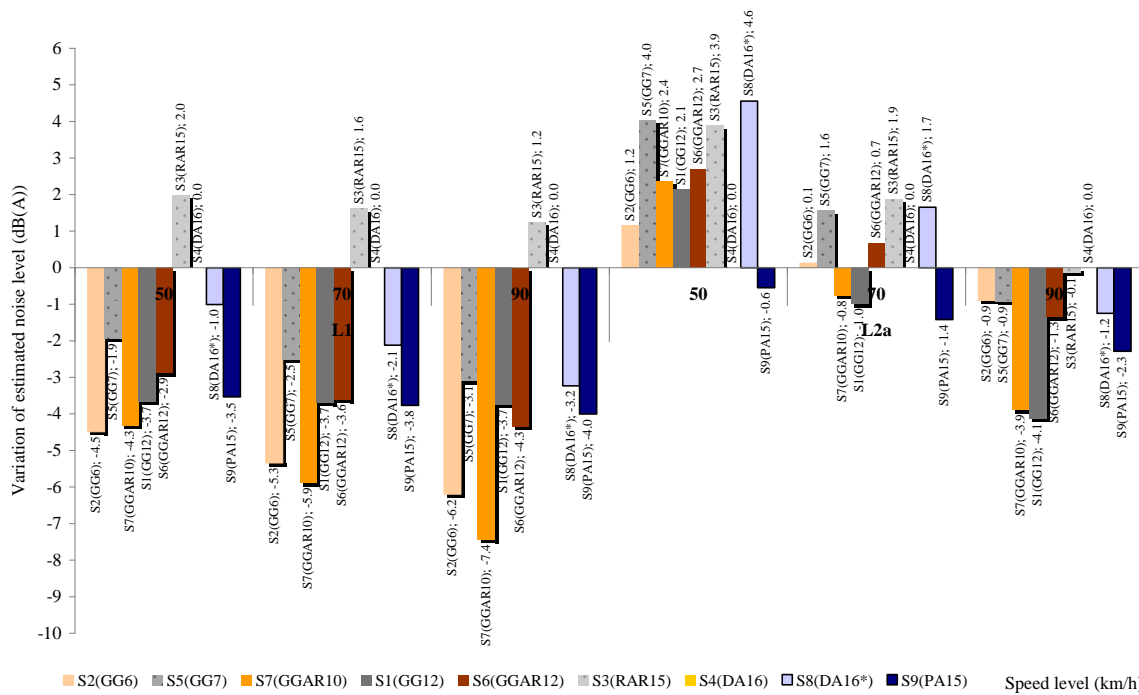


Figure 6 – Variation of the estimated noise level regarding surface of reference S4 versus speed (surfaces sorted into the increasing MAS)

CONCLUSIONS

This paper deals with the noise produced in nine selected surfaces, seven of which on road sections under traffic loading and two on a motorway under construction. The noise tests were based on the Controlled Pass-by Method. They were carried out using three categories of vehicles at speeds ranged from 50 km/h to 100 km/h. From the analysis of results regarding noise level versus speed, estimated noise level versus type of surface and estimated noise level versus reference surface, the following conclusions may be stated:

- Noise levels increases the most with speed on surface S4(DA16);
- Noise levels increases the least with speed on surface S7(GGAR10);
- The water on the surface does not seem to increase the slope of the curve noise level versus speed for the light vehicles;
- If the surface is dry, noise generated by heavy vehicles generally depends less on speed than noise generated by light vehicles. If the surface is wet the slope of the curve noise level versus speed doubles for dense asphalt and porous asphalt;
- For both cases and considering the three speed levels and light vehicles, surfaces S2(GG6) and S7(GGAR10) generate the lowest noise levels, surfaces S1(GG12), S6(GGAR12) and S9(PA15) generate slightly higher levels and S3(RAR15) generates the highest noise level values;
- For heavy vehicles, at 70 km/h and 90 km/h, surfaces S1(GG12), S7(GGAR10) and S9(PA15) are the most silent;
- In relative terms, surface S3(RAR15) increases noise regardless the testing conditions;
- For heavy vehicles at 70 km/h, surfaces S1(GG12), S7(GGAR10) and S9(PA15) slightly reduce noise. At 90 km/h a reduction of about 4 dB(A) for surfaces S7(GGAR10) and S1(GG12) was estimated;
- For light vehicles, the noise abatement provided by surfaces S2(GG6) and S7(GGAR10) for speeds of 50 km/h, 70 km/h and 90 km/h is about 5 dB(A), 6 dB(A) and more than 7 dB(A), respectively;
- Surfaces S1(GG12), S6(GGAR12) and S9(PA15) also have similar results, comprising reductions between 3 and 4.5 dB(A).

The best performances were achieved with gap graded mixtures, with and without rubberized binder, and small grain sizes. In this study the grain size and consequently the texture of the surface seems to influence the noise level more than porosity, as it can be observed by the fair behaviour shown by the porous asphalt.

In order to verify these results, further research on thin layers should be carried out. It should include a wider range of testing speeds for heavy vehicles, tests with wet surfaces, tests to provide texture spectrum and sound absorption tests.

The results will be then applied to reduce the tyre-surface noise by improving the acoustical and the mechanical behaviour of surfaces, with time.

REFERENCES

- Anfosso-Lédée F. (2001). The Effect of Temperature on Pass-By Noise. LCPC, Nantes, France.
- Andersen B., Bendtsen H. and Larsen L. (2006). Acoustic Performance of Low-Noise Road Pavements. Silvia Project Report, Denmark.
- ASTM E965-96 (2006). Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique. American Society for Testing and Materials.
- ASTM E303-93(2003): Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester. Volume 04.03, Road and Paving Materials; Vehicle-Pavement Systems. American Society for Testing and Materials.
- Bartolomaeus W. (2006). The Potential of Different Road Surface Designs in Road Traffic Noise Reduction – European Experience on Pavement Influence on Noise (Experiences in Germany). Jornadas Técnicas, Madrid 2006.
- Bendtsen H. and Andersen B. (2005). Noise-Reducing Pavements for Highways and Urban Roads – State of the Art in Denmark.
- Bendtsen H. (2006). Review of Existing Low Noise Surfaces. Jornadas Técnicas, Madrid 2006.
- Berengier M. (2005). Detection Systems for Pavement Discontinuities. Silence European Commission DG Research.
- Descornet G. (2005). Low-Noise Road Surfaces - European State of the Art. AAPT2005 Volume74.
- Descornet G. and Goubert L. (2006). Noise Classification of Road Pavements, Task 1: technical background information 1, Draft Report 05. Directorate-General Environment. European Commission.
- Donovan P. (2005). Comparative Measurements of Tire/Pavement Noise in European and the United States, the NITE-study, Illingworth & Rodkin, Inc., prepared for The California Department of Transportation.
- Freitas E., Pereira P., Picado-Santos, L., Santos A. (2006). A influência da Água no Ruído Produzido pelo Tráfego Rodoviário. Revista de Engenharia Civil n.º 26, Universidade do Minho, pp. 5-15, Portugal, 2006.
- Gomes L., Seixas P. (2006). “Utilização de Misturas Betuminosas com Betume Modificado com Borracha na obra do IC24, entre Freixieiro e Alfena”. Seminário LNEC/CRP - Pavimentos Rodoviários Verdes. Lisboa.
- Haberl J., Lengheim T., Pucher E., Litzka J., Bendtsen H., Watts G., Parry A., Anfosso-Lédée F., Sandberg U., LeLong J., Hamet J-F., Van Blokland G-J., Kuijpers A., Ejsmont J. and Mioduszewski P. (2005). Integration of Low-Noise Pavements with other Noise Abatement Measures. Report, SILVIA-TUW-052-04-WP5-220305.
- Houari A. (2004). Influence de la Rigidité de Chaussée sur le Bruit de Contact Pneumatique-Chaussée. Thèse de doctorat de l'Université de Technologie de Compègne.
- ISO 11819-1:1997. Acoustics – Method for Measuring the Influence of Road Surfaces on Traffic Noise – Part 1: Statistical Pass-By Method. International Organisation for Standardisation (ISO). Geneve, Switzerland.
- ISO 11819-2: 2000. Acoustics – Method for Measuring the Influence of Road Surfaces on traffic noise – Part 2: The Close Proximity Method. Draft Standard ISO/CD 11819-2 International Organisation for Standardisation (ISO). Geneve, Switzerland.
- ISO 13473-1:1997. Characterization of pavement texture by use of surface profiles – Part 1: Determination of Mean Profile Depth. International Organisation for Standardisation (ISO).

- Geneve, Switzerland.
- Mancosu F. (1999). TINO Project: an Overview. 1° International Colloquium on Vehicle Tyre Road Interaction “The Noise Emission”, Roma, Italy.
- Pucher E., Litzka J., Haberl J., Girard J., Ejsmont J., Lelong J. Hamet J-F., Sandberg U., Bendtsen H., Watts G., Parry A., Blockland G., Kuijpers A. (2006). Recommendations on Specifications for Tyre and Vehicle Requirements. Silvia Project Report, TUW-039-02-WP5-120304.
- Ruivo (2004). “Avaliação do Efeito do Pavimento no Ruído de Tráfego Rodoviário (II) – relatório de ensaios pavimento B.M.B. versus pavimento B.B.R.. CERTIPROJECTO/RECIPAV/AEA. Lisboa.
- Sandberg U., Ejsmont J. (2002). Tyre / Road Noise Reference Book. Informex SE – 59040. Kisa. Sweden (www.informex.info)
- Sandberg U. and Kalman B. (2005). The Poroelastic Road Surface – Results of an Experimental in Stockolm. Silvia Project Report, SILVIA-VTI-006-00-WP4-030605.
- SILVIA (2006). “Guidance Manual for the Implementation of Low-Noise Road Surfaces”. FEHRL report 2006/02. Forum of European National Highway Research Laboratories. Brussels. Belgium
- Watts G. (2005). Harmonoise Prediction Model for Road Traffic Noise. Published Project Report PPR034. TRL Limited.